Voltage Collapse & Control in Complex Power Grids

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Abstract

The ability of a large-scale power grid to transfer energy from producers to consumers is constrained by the network structure, by the nonlinear physics of power flow, as well as by operational limits. Any violation of these fundamental constraints has been observed to result in voltage collapse blackouts, where nodal voltages slowly decline before precipitously falling. In fact, the majority of recent blackouts in Western countries have been attributed to voltage collapse and related instabilities. The available methods to test for voltage collapse are dominantly simulation-based and offer little fundamental insight for the design of control strategies. Here we present a closed-form condition under which a power network is safe from voltage collapse. The condition combines the complex structure of the network with the reactive power demands to produce a node-by-node measure of network stress, lower bounding the distance to collapse and predicting the largest nodal voltage deviation in the network. We extensively test our prediction on large-scale systems, and demonstrate how our stability condition can be applied to increase grid stability margins through corrective control actions.